# Equitable Deep Decarbonization:

## a framework to facilitate energy justice-based multidisciplinary modeling

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**2022**

Please cite as:

Spurlock, C. Anna, Salma Elmallah, and Tony G. Reames. "Equitable deep decarbonization: A framework to facilitate energy justice-based multidisciplinary modeling." *Energy Research & Social Science* 92 (2022): 102808.
https://doi.org/10.1016/j.erss.2022.102808

This work was supported by the U.S. Department of Energy under Contract No. DEAC02-05CH11231.

# Equitable Deep Decarbonization: a framework to facilitate energy justice-based multidisciplinary modeling

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**Highlights:**

- Presents framework mapping energy justice to decarbonization pathways modeling.
- Calls for multidisciplinary research centering priorities of affected communities.
- Identifies steps to equitable deep decarbonization with practical considerations.
- A restorative justice lens highlights adaptation co-benefits of climate mitigation.

**Abstract:**
Persistent, systemic harms have resulted in inequalities in wealth distribution, energy insecurity, infrastructure reliability, heat island exposure, and preexisting health conditions, all of which have exacerbated climate change driven damages. Efforts to decarbonize our energy system to address the climate crisis must seize the opportunity to reduce inequality. Doing so requires a multidisciplinary approach to assess the tradeoffs between alternative decarbonization pathways. In this Perspective we introduce an Equitable Deep Decarbonization Framework for mapping the tenets of energy justice to the practice of large-scale deep decarbonization pathways modeling designed to facilitate this multidisciplinary effort. We provide discussion of key considerations for each step of the framework to enable modeling that accounts for adaptation co-benefits associated with systematic climate risks to vulnerable communities.

**Keywords:** energy justice, deep decarbonization, energy transitions, restorative justice, climate change, distributional analysis

# 1 Introduction

We introduce the Equitable Deep Decarbonization framework, which connects energy justice to large-scale deep decarbonization pathways modeling. If integrated into model development, this framework can identify optimal and equitable pathways to deep decarbonization. This framework creates a shared language between scholars and practitioners of energy justice and decarbonization modelers to enable meaningful collaboration. The audiences we seek to engage in this Perspective are (1) the practitioners of deep decarbonization modeling, by highlighting critical considerations and providing a starting point for integrating equity more directly into modeling, and (2) energy justice academics and practitioners, by providing language to translate energy justice priorities into concrete and tangible concepts for those engaged in more technical modeling. We call for this deep collaboration to yield equitable climate policy and to develop engagement, metrics, and guidance that are relevant to many levels of government as well as community and private sector stakeholders.

Faced with the pressing need to limit climate change to less than 2 degrees Celsius (2°C) [1], the world has embarked on a global transformation of every sector of the energy system. The European Union [2] and the United States [3] have established the target of net-zero emissions by 2050. The 2020s are the "decisive decade" to move swiftly and build out the enabling infrastructure necessary if these decarbonization goals are to be met [4–6].

In the U.S. context there has been a proliferation of studies that have assessed strategies for deep decarbonization [7] by estimating emissions reduction and monetary costs associated with different technology pathways. These studies can take several forms: top–down, scenario-based back-casting approaches identify a set of potential low-carbon technologies, then construct a scenario through which, using those technologies, the net-zero emission target can be achieved; top–down integrated assessment modeling (IAM) studies use IAMs of the climate and economic systems to develop a least-cost portfolio of technologies from the set of technologies available that enable the target to be reached, and can model how the optimal portfolio may change under alternative assumption of technology availability or costs; finally, bottom–up energy systems modeling studies use relatively detailed engineering representations of the energy system and technologies, and then similarly construct scenarios that meet the target based on these representations, which can allow for considerations of technology-specific constraints as well as some additional understanding of cost tradeoffs. For those interested in more detail, a review and description of all of these types of studies was conducted by Loftus and co-authors [8]. These decarbonization pathways studies generally take the stance that "All else equal, policy should be formulated to achieve the climate and health benefits of net zero at lowest possible cost" [7]. Multiple studies have found that net-zero emissions by 2050 can be achieved in the U.S. at relatively low aggregate cost [9,10]. For example, the Zero Carbon Action Plan (ZCAP) found that deep decarbonization in the U.S. could be achieved for only 0.4% of GDP more per year than the fossil-fuel-based economy as of 2050 [11].

Broadly speaking, most studies have tended to focus on potential decarbonization technology pathways at a high level, with very limited consideration of the policy or implementation pathways through which these technology scenarios might be achieved. While there are examples in which policy recommendations or considerations are discussed in detail, such as the ZCAP study mentioned above [11], and more recent work that grapples with the question of technology pathway feasibility and realism from a political perspective [12], the broad lack of focus on policy and implementation mechanisms generally limits the extent to which deep decarbonization studies, as historically conducted, can fully tackle the question of equity. Specifically, although decarbonization pathways studies may contain some discussion of socio-economic or political considerations [7], such as job creation or geopolitical competitiveness, those outcomes tend not to be directly modeled. We identify no large-scale comprehensive deep decarbonization pathways modeling effort in the U.S., or elsewhere, that has meaningfully centered equity and comprehensively assessed the distributional implications of the alternative scenario (particularly including policy and implementation) pathways. Implementing a modeling process based on the tenets of energy justice can enable decarbonization modeling that centers equity. This Perspective presents an argument for why equitable deep decarbonization is important and provides a framework to facilitate it.

# 2 Mapping Energy Justice to Decarbonization Pathways Modeling

Energy justice action and scholarship, which highlight the conflicts between global energy systems and vulnerable communities, grew out of the movement and scholarship of environmental and climate justice dating back to the 1980s and 2000s, respectively. Energy justice issues are intertwined with both technological and social elements of the energy system, with principles that range from *availability* to *intergenerational equity* to *intersectionality* [13].

The foundational concepts of energy justice have been set forth by multiple scholars [13–15]. Here, we focus on the "Four Tenets" of energy justice: procedural justice, recognition justice, distributional justice, and restorative justice. Each of these concepts are defined below, with additional definition and discussion provided by Heffron and McCauley [15], among others. This Perspective contributes to recent discourse around how to better operationalize energy, environmental and climate research with a focus on distributional outcomes, equity, and wellbeing. Narasimha Rao and Charlie Wilson present a call for an interdisciplinary research agenda to focus energy and climate research on human wellbeing [16]. Charles Lee presented a framework to integrate environmental justice into environmental policy decision-making [17]. Our framework, depicted in Figure 1, translates between those in the field of energy justice and those modeling pathways to deep decarbonization. Our mapping is also relevant to environmental justice, climate justice, and other contexts in which distributional analyses should be considered. To facilitate understanding for those less familiar with some of the terminology pertinent to the technical modeling side of this work, the Supplemental Information provides a table containing definitions of terms we use in discussing the framework.

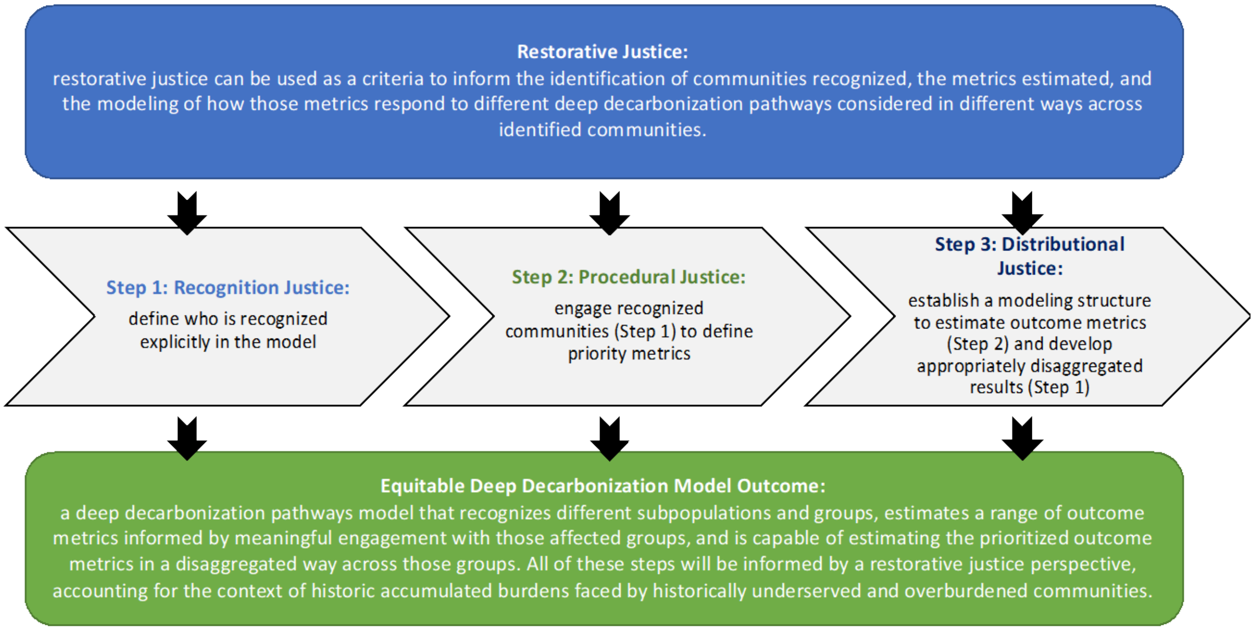


*Figure 1 Equitable Deep Decarbonization Framework. The framework maps the steps of model development to the tenets of energy justice, with the restorative justice tenet providing a foundation to each of the steps. The result is a deep decarbonization pathways model that centers energy justice.*

## 2.1 Restorative Justice Informs All Steps

Our framework is organized into three steps, each resulting in distinct decision points in modeling decarbonization pathways, and each involving a process component informed by energy justice. One of the tenets of energy justice is restorative justice. Rather than presenting restorative justice as a step in the framework, we argue that restorative justice is a critical context that informs all three of the framework steps. **Restorative justice** calls for a repair of harms done to communities and the environment. The economic efficiency-focused framework that undergirds most decarbonization pathways modeling studies, conducted at an aggregate national scale with a focus on cost and greenhouse gas mitigation metrics only, ignores past accumulation of injustices that have been disproportionately experienced by underserved and overburdened communities. A decarbonization pathways modeling approach rooted in energy justice would allow for restorative justice issues to surface at the outset of a study, informing Steps 1-3. In this way, restorative justice can be used as an ex-ante criterion to identify the communities recognized, metrics prioritized and estimated, and modeling approaches utilized. This expands upon past conceptualizations of restorative justice as an ex-post assessment of necessary compensation of harms imposed by a given policy.

In centering restorative justice as a modeling principle, we assert that modeling is not an objective, distant, apolitical project. As we argue below, modeling decisions–from the outcomes presented to the modeling structures considered–are shaped by those involved in decision-making. Social scientists have long argued that “whose knowledge is considered relevant has profound consequences for the shape of energy systems” [18]. A consideration of restorative justice pushes the current boundaries of "relevant knowledge" for deep decarbonization modeling beyond engineers, economists, and technocrats.

There are multiple considerations that might crystalize when approaching decarbonization pathways studies with a restorative justice lens. One particular consideration that we highlight throughout the framework is that of climate adaptation as a co-benefit of climate mitigation. This theme is used as a way to demonstrate the framework through highlighting concrete considerations for each step of the framework as presented below. This is, however, not the only overarching consideration that may need to be integrated.

## 2.2 Step 1: Recognition justice–define who is recognized explicitly in the model

Step 1 of our framework begins with **recognition justice**, which calls for recognition of the divergent perspectives relevant to energy and climate justice discourse; people with different social, cultural, ethical, racial, and gender backgrounds all have relevant and informative perspectives, opinions, and priorities that should be acknowledged and honored. For decarbonization pathways modeling, recognition justice at a minimum informs who is recognized explicitly in the model. In modeling terms, recognition is reflected in indices or characteristics used to identify different subpopulations or subregions for whom results of the model will be reported in a disaggregated way.

**Step 1 Process**: conduct a review of the literature, and discuss with multidisciplinary subject matter experts and community-based organizations to understand how risks, opportunities, and historic harms vary across different subpopulations, locations, and communities. Heavily leverage expertise from energy justice, climate justice, and environmental justice scholarship and practice. Take into account the restorative justice perspective by recognizing how the context of accumulated burdens and injustices have contributed to inequities in current resources, wealth, resilience, and vulnerabilities across different communities, locations and subpopulations. Through this process consider different potential identifiers for subpopulations or subregions to be explicitly recognized in the model.

**Step 1 Outcome**: a concrete set of indices or characteristics that will define heterogeneity in the model. For example, this might consist of indices defining a typology of different local geographies (such as census tracts in the U.S.) to identify those that are historically disadvantaged (which is the approach being taken in the U.S. implementation of the Biden-Harris administration's Justice40 initiative, which calls for 40% of benefits form clean energy and climate investments to go to disadvantaged communities [19], where those disadvantaged communities are being defined based on a census-tract-level set of indicators [20–23]). In other cases, it might be determined that one or more socio-economic characteristic (such as income, race, wealth, or age) is best suited to identify distinctions between different sub-populations, rather than location-based indices.

**Step 1 Considerations**: decarbonization pathways studies focus on climate change mitigation without accounting for how alternative technology and implementation pathways might impact the capacity of different communities to adapt to climate change. However, as Carlos Martin articulated, "climate mitigation and climate adaptation don't need to be at odds" [24]. When viewed through a restorative justice lens, the importance of considering climate adaptation in the context of climate mitigation studies crystalizes. A large body of research demonstrates that the climate crisis has disproportionately harmed people of color in the U.S. (where "people of color" is often defined based on U.S. Census questions: anyone who did not indicate their racial status as white alone, or indicated their ethnicity as Hispanic or Latino), and that this pattern is projected to continue. For instance, heat is among the deadliest of all weather-related disasters in the U.S. [25]. Vulnerability to heat is not experienced uniformly across the population; remote sensing data from 2013-2017 revealed that in all but six of the 175 largest U.S. urban areas, the average person of color lives in a census tract with a higher surface urban heat island intensity than the average non-Hispanic white person [26]. Of the heat-related deaths in New York City between 2000 and 2012, 50% were Black, whereas Black people made up only 25% of the city's population [27]. Black people in the U.S. are 40% more likely to currently live in areas with the highest projected increase in temperature-related deaths due to global warming of 2°C, and Latinx people are 43% more likely to currently live in areas with the highest projected heat-related labor impacts [28]. The severity of climate impacts experienced by communities of color also extends to failures of resilience of our energy system to climate-driven events. Those living in census block groups (a U.S. census geography that further subdivides census tracts) predominantly populated by people of color were more than four times as likely to experience a power outage during the February 2021 Texas grid failure than those living in predominantly non-Hispanic white census block groups [29]. The historic underinvestment, discrimination, and marginalization experienced by communities of color in the U.S. is the context from which they must face increasingly damaging climate change. In particular, this historic context mediates the capacity of these overburdened communities to adapt to climate impacts, and underscores the need for decarbonization strategies that simultaneously provide protection from severe heat exposure, and increased community resilience to acute climate-driven events. This context should motivate the selection of indicators, informed by the central lens of restorative justice, that capture populations that have experienced histories of injustice, cumulative burdens associated with the current energy system, or disproportionate barriers to adopting decarbonization technologies. Both geographic (i.e., heat island locations; projected climate-related heat event and disaster intensity), and socio-economic factors (income and race) should be considered in recognizing communities likely to face distinct outcomes with respect to climate adaptation from alternative decarbonization pathways.

## 2.3 Step 2: Procedural justice–engage recognized communities to define priority metrics

Step 2 invokes **procedural justice**, which asserts that underserved and overburdened communities should be engaged in decision-making, have a voice, be able to exercise "energy democracy," and have agency over their lives. Procedural justice requires routine engagement with stakeholders, including those communities and subpopulations identified in Step 1, which will surface less obvious issues, or issues historically ignored due to convenience, data availability, or researcher bias. Potentially affected communities must have a voice in defining priorities: in modeling terms, those priorities are reflected in the objective function in an optimization model, or primary outcome metrics in a scenario analysis.

**Step 2 Process**: conduct ongoing and meaningful engagement with underserved and overburdened communities, specifically as defined in Step 1, with the goal of identifying the critical outcomes that are priorities to these communities pertinent to the alternative technology pathways, as well as the potential policy or implementation mechanisms that can enable that technology scenario being considered in the model. Integrate the restorative justice perspective by recognizing that metrics or outcomes of value to affected communities may include addressing cumulative historic harms and burdens experienced due to the structure of the incumbent energy system, and formulate approaches to engagement with communities that facilitates a clear understanding of these factors.

**Step 2 Outcome**: a concrete set of metrics that can be defined in the model, and would be differentially affected by alternative technology and policy/implementation pathways that could be considered. Examples, often referred to as "co-benefits," might include wealth building; reduced energy burden; health improvements (due to air quality improvements or mold remediation, for example); increased access to opportunities; increased time savings or convenience; increased resilience to heat, weather, fire, wildfire smoke, or natural disasters; increased safety; improved employment opportunities; or increased autonomy or self-determination.

**Step 2 Considerations: "**meaningful engagement" is context-specific, and its structure can range from direct, compensated involvement of community members or leaders in line with Jemez principles [30] to energy justice advisory committees who have regular, direct input and influence; it can also draw on the reports, analyses, and articulations of priorities already published by community-based organizations in the study area. Regardless, procedural justice requires in-depth and sustained stakeholder engagement practices. One example of a model for such sustained and meaningful engagement is the knowledge co-production approach. This approach, which is defined as an "iterative and continual engagement between scientists and decision-makers," has been applied in the context of policy-relevant science for adaptation to climate change. Examples of this approach in practice in the U.S. include development of city-specific climate vulnerability assessments [31], and usable climate science relevant to a range of stakeholders [32]. In one such example, Project Hyperion used knowledge co-production techniques to develop metrics from climate models of most immediate value to water resource planners (e.g., the start date of the rainy season or number of extreme heat days may be more actionable than average temperature and precipitation) [33]. A similar meaningful knowledge co-production process can be employed in the context of deep decarbonization pathways modeling to define the most meaningful co-benefit metrics to include in the modeling for a range of policy makers, from federal to local, and including the perspectives, values, and priorities of communities themselves. Just as modeling projects often begin with a review of academic or industry literature, they can also include a review of community-based reports to begin establishing directions for metrics and further engagement. For example, the Asian Pacific Environmental Network (APEN), an environmental justice organization that convenes representatives and reviews research from environmental justice and labor organizations, has articulated some of the climate adaptation co-benefits relevant to vulnerable communities that could result from certain pathways to decarbonization. These include energy reliability and resilience, protection from extreme heat events, and protection from negative impacts associated with climate-driven disasters such as wild fires, among others [34]. These are some example co-benefits, but employing the proposed Equitable Deep Decarbonization Framework would engage the communities recognized in Step 1 to identify a wider range of potentially important co-benefits, or co-costs.

## 2.4 Step 3: Distributional justice–establish a modeling structure to estimate outcome metrics and develop appropriately disaggregated results

Because the effect of greenhouse gas emissions on global climate change is location-agnostic (i.e., emissions affect climate change equally regardless of where they occur) there has historically been limited focus on distributional analyses in the context of climate mitigation. This perspective has carried over into deep decarbonization pathways modeling. However, while climate change is global, the impact of climate change is not felt uniformly, and the specific prevalence of co-benefits to climate mitigation measures vary significantly from location to location and subpopulation to subpopulation, depending on the policy or implementation mechanisms for those mitigation technologies or measures. Indeed, the primary focus of deep decarbonization models and studies historically has been on the technologies broadly, with simplified assumptions or a lack of explicit consideration of how those technology pathways might be implemented in terms of policies. However, it is precisely the policy mechanisms or specific technology implementations strategies that will result in meaningful differences in outcome metrics from Step 2 as realized in different subpopulations recognized in Step 1.

Step 3 aligns with **distributional justice**, which sets forth that environmental, energy, climate, and other benefits and costs should be equitably distributed across communities. From a modeling perspective, considering distributional justice ensures that the outcome metrics identified in Step 2 are estimated and presented at a sufficient level of disaggregation to reflect impacts on the populations identified and engaged in Steps 1-2.

**Step 3 Process**: assess alignment of modeling choices (e.g., detail with respect to potential policy or implementation pathways scenarios coupled with technology scenarios, levels of aggregation, functional forms, modeled relationships and sensitivities) to ensure that the disaggregation level defined in Step 1 can be achieved, and that the sensitivity of the metrics defined in Step 2 to alternative technology and policy pathways are being captured in the model. A restorative justice perspective informs this step through a recognition that the response of outcomes in different communities to different policies, technology options, or similar interventions, are likely to be a function of their historic baseline context.

**Step 3 Outcome**: a model or integrated sequence of models capable of measuring the metrics defined in Step 2 at the level of disaggregation defined in Step 1.

**Step 3 Considerations:** when assessing modeling structure and choices the following factors, at a minimum, need to be considered: (1) policy and implementation pathways modeling; (2) model resolution; and (3) disaggregation in response functions. Each consideration is discussed in turn below.

1. **Policy and implementation pathways modeling**: As mentioned above, the majority of deep decarbonization studies lay out at a very high level the extent to which certain technology mechanisms need to be employed to reach the net-zero target. For example,

the ZCAP study set forth key sectoral benchmarks that would need to be achieved, one of which pertained to "Renewable Power," (i.e., wind and solar capacity), broadly, noting the need for 500 gigawatt (GW), 1500 GW, and more than 2500 GW renewable capacity by 2030, 2040 and 2050, respectively [11]. However, it was not prominently discussed what different policy (e.g., incentives, pricing, mandates) or even implementation concepts (utility scale, community scale, residential rooftop photovoltaics (PV)) for that renewable power capacity benchmark underlay the assumptions in the EnergyPATHWAYS and RIO models they employed. The ZCAP study is an example of an IAM study, and did, more so than many, undertake a significant discussion of policy and implantation considerations. However, with respect to the modeling and specific outcomes analyzed, still remained largely constrained to high-level technology pathways with no formal modeling of policy or implementation pathways, and remained narrowly focused on cost and emissions mitigation in terms of the outcome metrics modeled, with the exception of an analysis of jobs and employment impacts, which were modeled at a national scale [11]. We refer to the ZCAP study as a concrete example in making our point about the first Step 3 consideration not because the ZCAP study is particularly lacking among examples of deep decarbonization studies, but rather because it is one of the most comprehensive examples with respect to their discussion of just transition considerations and policy recommendations we reviewed, and so provides a valuable jumping off point. While the RIO model employed in the ZCAP study is designed to find the least cost supply of energy needed from the scenario, the tradeoffs between different implantation pathways and policies can have very different co-benefit outcomes for different subpopulations. For example, the APEN report mentioned previously articulates the value of distributed energy systems, such as rooftop solar with storage and microgrids, to medically dependent populations and working-class communities of color for energy reliability and resilience in the face of increasingly frequent extreme weather events [34]. In contrast, these co-benefits would not materialize in the case of utility-scale renewable pathways. Comparing these alternative solar implementation pathways (utility scale, community scale, and rooftop, with or without storage) resulting in the same level of carbon mitigation might cost different amounts, but also might result in differing amounts of these co-benefits. Step 3 within our proposed framework would require studies to implement models enabling specification of different policy and implementation pathways for a given technology pathway and estimate how specific implementation pathways would result in different magnitudes of co-benefits prioritized by affected communities as identified in Step 2 across identified communities and subpopulations engaged in Step 1.

2. **Model resolution**: Many deep decarbonization studies in the U.S. are focused on presenting results at a nation scale [7,11]. However, beyond enabling insights at different geographic scales, a modeler's choice of spatial resolution also has fundamental implications for the national-level conclusions drawn from results. For example, increasing the resolution of damage modeling to county- rather than national-level has uncovered non-linear impacts that can change the overall estimation of climate change damages [35]. In another example, because of the correlation between the location of particulate emissions and where people tend to live, Tessum and co-authors [36] found that when the spatial grid resolution of their air quality model was 4km, the aggregate population-weighted concentration of $PM_{2.5}$ was 15-20 percentage points higher than if

the grid resolution of the model were at a lower resolution of 36km. The national resolution top-down models used by most deep decarbonization studies do not account for underlying non-linear relationships revealed by modeling at more disaggregated spatial (e.g., census tract or census block) or socioeconomic resolution. While the emphasis has been on the technology pathways alone, this has been less of a focus, but when considering the implications of different implementation strategies and policies, as described in the first Step 3 consideration, this becomes of critical importance. A national resolution not only precludes assessment of the distributional outcomes of the scenarios, which could inform a wider set of decision-makers on a justice-oriented set of metrics, but also inaccurately captures the national-level bottom-line tradeoffs between potential decarbonization pathways. Spatial disaggregation is particularly important if deep decarbonization studies are to be relevant to decision-makers who do not work at a national scale. The decision-makers that will be implementing energy transition policies will represent a diversity of sectors and geographic scales, from federal, to state, county, and city government, as well as communities, advocacy groups, and the private sector.

3. **Disaggregation of response functions**: there are two different approaches to distributional analyses: (1) the response of an outcome to an intervention is modeled in the aggregate, and a post-assessment can then demonstrate how the aggregate outcome might be distributed across two subpopulations, without necessarily accounting for different response functions those two subpopulations might have; or (2) the response to the intervention is modeled separately for different subpopulations, accounting for the different baselines of each subpopulation *and* their potentially different responses to the intervention, possibly as a function of that baseline. It is important to try and conduct modeling using the latter approach wherever possible. An example of why this consideration is important relates again to the role of climate adaptation in driving the differential co-benefits of different climate mitigation pathways. Specifically, many of the damages from climate change have non-linear relationships with income [37,38]. The direct effect of climate change is that it worsens negative economic outcomes and results in increased mortality. However, due in part to adaptation status, these negative outcomes are less severe in regions that have already adopted significant adaptive measures (e.g., air conditioning) than those that have not [39]. Importantly, current adaptation status is a function of current and historic income [38]. This means there are two interconnected pathways to mitigating damage from climate change: first, reducing emissions, and second, increasing adaptation status, which would depend on the implementation pathway or policy considered to enable that level of mitigation, and the mechanisms through which those different implementation pathways would affect adaptation (e.g., extreme temperature protection due to improved building envelopes, air conditioning, increased energy security, reduced energy burden). The modeling of this latter pathway requires a disaggregated framework in which the modeled benefits of a specific decarbonization strategy are a function of the baseline conditions of the population. Fully accounting for both requires modeling of alternative policy and implementation pathways conducted at a sufficiently high level of spatial resolution, as well as modeled relationships responsive to underlying heterogeneity, to capture non-linear correlations between population characteristics, climate impacts, and co-benefits associated with climate adaptation. No deep decarbonization studies to-date have done this.

# 3 A Call for Equitable Deep Decarbonization

In the U.S., historic underinvestment and discrimination have led to inequities in wealth distribution, energy insecurity, infrastructure reliability, heat island exposure, and preexisting health conditions, all of which structure vulnerability to climate damages. Researchers and analysts who employ modeling to formulate a path forward need to center restorative justice. A recentering of modeling around restorative justice shifts who is recognized in models, the process by which they are included in defining critical metrics, and the tools that identify the best path (including technology as well as policy/implementation) to climate crisis solutions. Many deep decarbonization studies point to a list of "no regrets" solutions [7,40]. These "low-hanging fruit" are actions that modelers argue should be taken now, even though technology uncertainty in the future remains. But without a modeling framework that accounts for the significant community and societal co-benefits or costs that some, but not all, decarbonization investments and policies present, the optimal path forward cannot be fully assessed. As a society we need to make sure the actions taken are truly "no regrets."

The proposed Equitable Deep Decarbonization Framework provides a shared language that affected communities, researchers, scholars, and modelers from varied backgrounds and disciplines can use to fruitfully collaborate to solve the pressing need to address climate change, and do so in a way that realizes all potential benefits and costs from the energy transition for all communities, particularly those most vulnerable to the impacts of climate change. Such multidisciplinary, boundary-crossing, collaboration is critical to success. Equitable Deep Decarbonization is an opportunity to jointly accomplish the goals of addressing climate change, while maximizing the multiplicative benefits potential of mitigation measures.

**Acknowledgements**
The authors would like to thank Shalanda Baker for providing early direction and ongoing guidance for this paper, and Leslie Aguilar, Anjuli Jain Figueroa, Sydney Forrester, Jenny Heeter, Miguel Heleno, Natalie Popovich, Michael Reiner, Monisha Shah, and Benjamin Sigrin for their helpful discussion during conceptualization and thoughtful feedback on earlier drafts of this work. In addition, the authors would like to thank the very thoughtful anonymous peer reviewers whose helpful comments enabled a much stronger paper in preparation for publication.

**Funding**
This manuscript has been authored in part by authors at Lawrence Berkeley National Laboratory under Contract No. DEAC02-05CH11231 with the U.S. Department of Energy, Office of Economic Impact and Diversity. The U.S. Government retains, and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains, a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for U.S. Government purposes.

**Declaration of Competing Interests**
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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